IB/05/051117

Europäisches Patentamt | **European Patent Office** | **Office européen des brevets**

Bescheinigung | Certificate | Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. | **Patent application No.** | **Demande de brevet n°**

04101475.4

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

Anmeldung Nr:
Application no.: 04101475.4
Demande no:

Anmeldetag:
Date of filing: 09.04.04
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

Koninklijke Philips Electronics N.V.
Groenewoudseweg 1
5621 BA Eindhoven
PAYS-BAS

Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

High-pressure sodium lamp

In Anspruch genommene Prioriät(en) / Priority(ies) claimed /Priorité(s) revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

H01J61/82

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LU MC NL
PL PT RO SE SI SK TR LI

High-pressure sodium lamp

The invention relates to a high-pressure sodium (HPS) lamp suitable to be operated at a very high frequency (VHF). When operated the lamp is driven by a full electronic driver also known as a full electronic ballast. The frequency is preferable taken above the region in which acoustic resonance might occur in the lamp.

Known HPS lamps are provided with a discharge vessel or discharge tube, having a ceramic wall. Ceramic means in this context a wall made of crystalline metal oxide, like mono crystalline sapphire or densely sintered poly crystalline metal oxide, for instance poly crystalline alumina (PCA) and YAG, or metal nitride like AlN. These materials are well known in the art for their ability to be prepared with good translucent properties.

In this description and these claims discharge vessel, discharge tube and burner are equivalent of each other.

The power for which the lamp is designed is called the nominal lamp power (Pla).

What is known on the subject.

Standard HPS lamps are designed for operation on conventional ballasts, mostly having an inductive element as current stabilization. On such ballasts the standard HPS lamps, known as SON Plus 50, 70, 100 and 150 W lamps have efficacies of 83, 90,105 and 117 lm/W respectively. The lamp voltage (Vla) of these lamps is in the range of about 90 to 100V. To arrive at an acceptable compromise between lamp efficacy and field strength an amalgam composition with a sodium mole fraction (smf) between 0.663 and 0.739 is chosen. The resulting electrode distances are 37, 39, 45, and 59 mm for SON Plus 50, 70, 100 and 150W lamps respectively.

During lamp life of a known lamp the lamp voltage increases and with operation on a conventional ballast also the lamp power increases, which results in an increase of the wall temperature of the discharge tube of the lamp. Beside, also the mains voltage can vary, which can result in a higher lamp power and a consequently increase of the wall temperature. The SON Plus lamps are designed to be able to withstand these higher wall temperatures to a large extend. Therefore the lamp is designed such that the initial (100 h) wall temperature during operation at nominal power will be relatively low (below 1500 K).

In this respect the thickness of the PCA wall is chosen relatively high (0.6 -1.1 mm). A relative thick wall requires a relatively small tube diameter to arrive at acceptable values (> 1400 K) for the wall temperature. Too low values of the wall temperature result in loss of lamp efficacy and consequently in unacceptable low values for said lamp efficacies.

Besides limiting the wall temperature a relative thick wall will also reduce thermal stress and thus counteract the danger of cracking of the PCA wall during run up and cooling down of the lamp.

The starting gas pressure for reliable igniting the lamp is relatively low. In SON-Plus lamps Xe is used as starting gas with cold pressures below 300 mbar (at room temperature). To further facilitate ignition the discharge tubes are commonly provided with an antenna. The Xe pressure (p_{Xe}) is low in order to guarantee an ignition voltage below 2800 V (determined by IEC norm) at the relatively large electrode distances.

During a certain period in the run up phase of the lamp on a conventional ballast the lamp current is about twice as high as in stationary operating conditions. Electrodes are designed for this high initial current. They are thus relatively heavy for the considerably lower currents during nominal operation.

Standard SON Plus lamps are operated on conventional ballasts with relatively high ballast losses and with variations in lamp power during life-time.

The known lamps as described above are well designed for operation on a conventional ballast. Today's luminaires are optimised for these lamp and ballast combinations.

However, new full electronic drivers fulfilling the ballast function offer a number of new system opportunities in miniaturisation, design and energy saving, which all also result in cost savings.

These new opportunities are missing with the presently known lamps operated on conventional inductive ballasts, which is considered as drawbacks of the known systems.

Free choice of lamp voltage and thus of electrode distance. The required lamp voltage of about 100 V (at 220V mains) for the presently known lamps has a disadvantageous consequence for lamp length and thus system efficacy, because long lamps show a lower optical efficacy in general lighting applications, like for instance street lighting, than shorter lamps.

Control of lamp power Pla and thus of the wall temperature Twall. With a full electronic driver providing the ballast function power variations (and thus wall temperature variation) due to mains voltage variations and/or due to Na loss during lamp life can be

overcome by lamp power control, preferably by power stabilisation. The requirement for relatively thick walls (0.6-1.1 mm) combined with relatively small tube diameters will then expire. New optimal choices become possible for these lamp parameters in order to optimise the lamp or system efficacy. Higher lamp efficacies with thinner walls and larger tube diameters are possible. This can be translated in lower lamp power if lamp fluxes should be kept the same.

Control of the current and/or power during run-up. If the maximum run-up current can be kept equal to the nominal lamp current (in steady state operation) the power dissipated during run up will be significantly lower than in the case of the known lamp operated on a conventional ballast, for which the lamp current during ignition and run-up can be as high as twice the lamp current during steady state operation. Thick walls to minimise temperature gradients as function of time and thus to avoid cracks during run-up are not necessary anymore.

Shorter electrode distances, in the case of operation on full electronic driver, make higher Xe pressures possible. Also resonant ignition, easy realisable in VHF drivers, leads to a lower ignition voltage and thus to the possibility to apply higher Xe pressures. An antenna will no longer be indispensable for reliable ignition of the lamp. Without antenna a slightly higher lamp efficacy will be achieved.

Increase of the Xe pressures has a positive influence on several lamp characteristics: voltage, efficacy and maintenance.

With full electronic ballasts the run-up currents can be controlled. If the maximum run-up current is kept equal to or below the nominal current, electrodes can be optimised for nominal operation, which means that the electrode diameter can be much smaller. On the contrary shorter electrode distances will lead to lower lamp voltages and thus higher currents, which requires larger electrode diameters. The resulting electrode diameter in these new invented lamps will hardly deviate from the electrode diameter in existing SON lamps in spite of the much higher nominal current. The fact that these new electrodes are in fact optimised for as well run-up as nominal operation means that the chance on sputtering or melting is lower, which will result in a better maintenance.

The relatively high ballast losses of about 14W in a 70W conventional ballast and about 18W in a 150W ballast can be reduced significantly with the use of a full electronic VHF ballast. VHF ballasts for the 65 W and 140W lamps according to the invention show losses of respectively 6 and 12 W only. This leads to a higher system efficacy

We propose a series of new invented lamps, suitable to be operated on VHF ballasts.

These miniaturised lamps should be applied in miniaturised luminaires.

The lamps are designed in such a way that a compromise is found between optimal system efficacy, miniaturisation, and energy saving. The resulting systems are more attractive in general lighting, like street lighting applications than the existing ones.

For the burner or discharge tube a combination of the following measures is necessary to come to these new optimal lamp designs on full electronic ballasts:

Choose short electrode distances (ed) (roughly about half of the existing ed): $0.15 \leq ed/Pla \leq 0.40$ (wider range), preferably $0.2 \leq ed/Pla \leq 0.35$ (narrow range) for 40-140W SON lamps with as consequence $40V \leq Vla \leq 65V$.

Choose an amalgam composition with $0.6 < smf < 0.75$ as a compromise between efficacy and field strength optimisation.

Choose a large internal tube diameter (D_{int}) (for instance 5-7.5 mm for the SON 90 -140W types and 3-5 mm for the SON 40 - 65W types) in relation to the nominal lamp power Pla to optimise the lamp efficacy : $0.04 \leq D_{int}/Pla \leq 0.1$ (wider range), preferably $0.045 \leq D_{int}/Pla \leq 0.08$ (narrow range).

Choose the wall thickness (wt) as small as possible for all lamp types: $0.4 \leq wt \leq 0.6$ mm to keep the wall temperature high enough ($\geq 1450K$) at large tube diameters for optimal luminous efficacy.

Choose 400 mbar $\leq p_{Xe} \leq$ 1000 mbar to improve lamp efficacy and maintenance, while at the same time sufficient low breakthrough voltages can be maintained.

Choose a small electrode rod diameter with respect to the applied nominal and run-up current to minimise electrode losses and avoid sputtering or melting. The electrode diameter can be specified relatively to the average lamp current (I_{la}) at nominal lamp power by: $0.2 < (D_{electrode})^2 / I_{la} < 0.45$ (wider range), preferably $0.25 < (D_{electrode})^2 / I_{la} < 0.35$ (narrow range).

Operate the burner on a VHF ballast, preferably of single stage construction to minimise ballast losses. In addition preferably use resonant ignition to lower the maximum ignition voltage to 2kV

Ad 1

On an electronic ballast one is free to choose the lamp voltage, on a conventional CuFe ballast one is not. A shorter light source (shorter electrode distance) gives

the possibility to bundle the light emitted from the luminaire more effectively with as consequence a higher flux on the surface to be illuminated.

Consequences of a shorter electrode distance are:

a lower lamp voltage and thus a higher lamp current resulting in higher power losses in the ballast a decrease in efficacy of the lamp (especially if Hg rich amalgam is used to limit the voltage drop).

The optimal system efficacy will thus be a compromise between lamp, ballast and luminaire efficacy.

A lower electrode distance and thus a higher lamp current in combination with a high ballast efficiency (> 90%) will only be possible if a VHF ballast is used.

In a VHF ballast the losses are significantly lower than in conventional ballasts: 6 and 12 W for respectively a 66 and 140W lamp according to the invention with Vla = 55V compared to 14 and 18 W for respectively known 70 and 150W SON Plus lamps with Vla = 100V.

Experiments with recent and former luminaire designs show that significant shorter ed's (50 % shorter) will lead to an increased flux on the illuminated surface of at least 10% at equal luminaire size. For miniaturised luminaires this increase is still 5 %. The lamp efficacy losses due to shorter ed's should thus stay at least within this range, but preferably the lamp flux should be equal or even slightly higher to come to energy savings at equal lamp flux.

Figure 1 shows some calculation results of lamp efficacies as function of ed for a 66W and 140W lamp. If 10 % efficacy loss of the lamp is accepted, with respect to an ideal design of the known lamp, ed should have a minimum value of about 22 mm at a calculated wall thickness of 0.56 mm for the 66W lamp and for the 140W lamp a minimum value of about 32 mm at a calculated wall thickness of 0.5 mm.

These ed values will be even somewhat lower because of the fact that the actual efficacy values achieved with the known lamp design rules at ed = 35 mm (for the 66W lamp) and at ed = 55 mm (for the 140W lamp) are somewhat less than the indicated high values in the graph of figure 1. This is due to the actual need to use a somewhat thicker discharge tube wall than is used in the calculations according to the known lamp design rules.

The calculated efficacies of such 66W and 140W burners according to the invention are respectively 100 and 124 lm/W, which correspond very good with measured values of practical embodiments.

Compared to the efficacies realised with known 70W and SON 150W SON Plus lamps (90 and 117 lm/W respectively) this is clearly higher, in spite of the shorter ed.

For such a 66W and 140W lamp according to the invention ed/Pla is:

22/65 = 0.34 (66W)

32/140 = 0.23 (140W).

For a comparable known SON Plus 70W and 150W lamp ed/Pla is:

40/73 = 0.54 (70W)

64/154 = 0.41 (150W), which are significant higher values.

For these calculations, a 800 mbar Xe pressure is used for all electrode distances resulting in comparable efficacies at strongly reduced electrode distances. In the practical situation however, ignition is improved using shorter electrode distance. This means, a higher Xenon pressure, leading to a higher efficiency, with a similar ignition behaviour, can be used for shorter electrode distances. This increases the lamp efficiency further for short electrode distances.

Optimal arc efficacies can be achieved with a smf between 0.75 and 0.9. A lower smf leads to a higher lamp voltage, which would result in a lower current and thus a reduction in electric losses, however at the expense of a lower efficacy. In figure 2 the efficacy of the arc (not lamp efficacy !) is shown as function of the smf at a constant ed and at a Na pressure corresponding with delta lambda Na = 10 nm. Herein delta lamda is defined as the wavelength separation between the maxima of the self-reversed sodium D-lines in the spectrum of the light generated by the discharge tube. From figure 2 it can be deduced that if a drop in arc efficacy of more than 10 % should be avoided smf should be larger than 0.6. Smf values between 0.6 and 0.75 are recommended as a compromise between efficacy and lamp voltage.

Ad 2

Large internal diameters lead to more efficient HPS lamps. If these diameters are combined with thin tube walls the lamp efficacy will increase even more. The wall thickness is limited of course by the maximum allowable wall temperature. On full electronic ballasts, the lamp power is stabilised independent of Na loss and mains variations. Through the lamp power stabilization the wall temperature is controlled. This means that initially a higher wall temperature is allowed in comparison to the known lamp operated on a conventional ballast, resulting in a higher lamp efficacy. On the contrary thin walls at high Twall increase the risk of fast Na loss. Therefore it is advisable to keep the wall temperature

below 1550K. These requirements lead to an optimal wall thickness of: 0.4 mm ≤ wt ≤ 0.6 mm.

Figure 3 shows the calculated lamp efficacies as function of the outer discharge tube diameter (dt). The elctrode distance ed is kept constant as well as the value for Twall. As a consequence the value for the wall thickness varies along each curve shown. The resulting values for wt and D_{int} are shown in frames at several points along each curve. The graphs show that for a 140W lamp with discharge tube with large outer diameter of 7.5mm having a thin wall of 0.4mm the efficacy is about 125lm/W. A 90W lamp according to the invention can achieve a luminous efficacy of about 114 lm/W at an outer dt diameter of 7.3 mm corresponding with an internal diameter D_{int} of 6.5 mm.

The corresponding values for D_{int}/Pla of lamps according to the invention are:
6.5/90 = 0.07 for a 100W lamp
6.7/140 = 0.048 for a 140W lamp.

For known SON Plus 70, 100 and 150W lamps these values are respectively 3.8/73 = 0.052, 4.0/100 = 0.04 and 5.0 /154 = 0.032 (a clear shift of this area).

Taking a 15% smaller D_{int} at constant ed and keeping Twall constant result in the lamps according to the invention in a significant loss of luminous efficacy, which put a limit to further decrease of D_{int}.

A wall thickness of 0.6mm in the 140 W lamp, corresponds with a D_{int} of about 5.2 mm. The calculated efficacy has dropped to about 120 lm/W. In the 90W lamp the calculated efficacy decreases to about 111lm/W when the wall thickness is increased to 0.6mm corresponding with a D_{int} of about 4.5mm and a dt of about 5.7.

The measures described under 1 and 2 result in the invented lamps in a ratio ed/ D_{int} of at most 7, preferably at most 6.5, more preferably between about 5.5 and 4.0. For the known SON Plus lamps this ratio is above 10 and increases with increasing nominal power to values above 12.

The wall load of the invented lamp is in the range of 15 to 25 W/cm^2, preferably in the range of 18 to 23 W/cm^2, however should not exceed 30 W/cm^2. Wall load is herein defined as the ratio between the nominal lamp wattage and the internal tube surface over the electrode distance ed.

Ad 3

A higher p_{Xe} is advantageous for several lamp parameters: lamp efficiency, lamp maintenance and wall temperature. The most important restriction towards a higher xenon pressure is increase in the required ignition voltage.

For the lamp according to the invention the pulse ignition voltage is given as function of the xenon pressure in figure 4.

If a resonant ignitor is used, even lower ignition voltages are sufficient to guarantee a reliable ignition. A 2kV ignition voltage is chosen for a 140W lamp according to the invention with 550 mbar xenon pressure. The resonant ignition voltage is kept relatively low to keep the ballast price and dimensions low.

Ad 4

With a full electronic ballast the electrode dimensions can be minimized (minimal conduction losses). The run up current can be controlled (kept below the same level as in steady state) and lamp power can be stabilised (no consequences of mains voltage variation and Na loss on the lamp voltage and power). So the electrode, optimised for nominal operation will not be overheated during run-up. The dimensions of the electrode can be defined relative to the current through the lamp during as well run-up as steady state operation. Because of the fact that heat conduction is related to the cross section of the electrode $(D_{el})^2/I_{la}$ has been chosen as parameter to specify the limits for the electrode dimensions. For 66 and 140W lamps according to the invention several electrode diameters have been tested. The best results are obtained with D_{el} is 0.6 and 0.9 mm for corresponding currents of respectively 1.2 and 2.55 A.

For $(D_{el})^2/I_{la}$ this means:

0.36/1.2 = 0.3 (66W)

0.81/2.55 = 0.32 (140W)

For comparable SON Plus 70 and 150W lamps $(D_{el})_2/I_{la}$ is:

0.36/ 0.7 = 0.51 (70W)

0.81/1.5 = 0.54 (150W), clearly different

The optimised lamp according to the invention preferably has a nominal power in the range from 40 to 140W.

Several lamp embodiments have been made and tested. The most relevant data are shown in a table below.

Nominal lamp power Pla (W)	**66W**	**140W**	**90W**
PCA dimensions			
Internal diameter (mm)	4.50	6.31	5.2
D_{int}/Pla (mm/W)	0.068	0.045	0.58
Wall thickness (mm)	0.54	0.51	0.51
Filling			
amalgam compostion	15 mg Na/Hg (smf = 0.630)	20 mg Na/Hg (smf = 0.684)	20 mg Na/Hg (smf = 0.680)
Xe pressure (room temperature) (mbar)	568	442	442
Electrode			
Electrode distance (ed) (mm)	22.6	32	27.8
Electrode rod diameter (mm)	0.600	0.900	0.730
Ed/Pla	0.34	0.23	0.31
Lamp operaring data			
Lumen output (lm)	6711	17439	9816
Lamp Efficiency (lm/W)	102	125	109
Lamp voltage (V)	53.4	53	52
Lamp current (A)	1.24	2.6	2
Wall load (W/cm^2)	20.7	22.1	19.8
Twall	1450	1550	1500
Colour temperature T_C (K)	1934	2014	2032
Colour rendering index Ra_8/Ra_{14}	30/12	31/14	28/-

The light spectrum generated by each embodiment corresponds with values for delta lambda Na of about 10nm.

A single stage VHF ballast is used with a high efficacy (90%). The frequency varies from 150 kHz for 140W to 200 kHz for 65W. The operation frequency is chosen above the acoustic resonances. A 2 kV resonant igniter is used. Preferably use is made of the 3rd harmonic frequency of the VHF lamp operating frequency during the ignition process.

Run up current is approximately equal to the nominal current or slightly larger. It allows the choice of relatively thin electrodes.

The lamp is provided with an outer bulb enclosing the discharge tube and provided with a lamp base having electrical connections for connecting to a power source. The enclosed space between the outer bulb and the discharge vessel is preferably vacuum. Fillings of this space with nitrogen or any other inert gas are known in the art. Though higher wall loadings of the discharge tube will be possible, experiments have shown that in the end there is always a loss in efficacy.

Figure 5 shows an embodiment of the invented lamp. The figure is not to scale.

CLAIMS:

1. High pressure sodium lamp having a nominal power Pla, which is suitable to be operated at a very high frequency (VHF), having a discharge tube with a ceramic wall and an internal vessel diameter D_{int}, enclosing a discharge space in which a pair of electrodes at a mutual electrode distance ed and a filling of Na-amalgam with a sodium mol fraction (smf), characterized in that the discharge tube has a ratio ed/ D_{int} of at most 7, preferably between about 5.5 and 4.0.

2. Lamp according to claim1, characterized in that the wall thickness (wt) is $0.4 \leq wt \leq 0.6$ mm.

3. Lamp according to claim1 or 2, characterized in that the lamp has a wall load of at most 30 W/cm^2.

4. Lamp according to claim1, 2 or 3, characterized in that:
$0.15 \leq ed/Pla \leq 0.40$, preferably $0.2 \leq ed/Pla \leq 0.35$;
an amalgam composition with $0.6 < smf < 0.75$;
the ratio internal discharge vessel diameter D_{int} to the nominal lamp power Pla is $0.04 \leq D_{int}/Pla \leq 0.1$, preferably $0.045 \leq D_{int}/Pla \leq 0.08$;
the wall thickness (wt) is $0.4 \leq wt \leq 0.6$ mm.

5. Lamp according to claim1, 2, 3 or 4, characterized in that the filling also comprises Xe having a pressure at room temperature in the range of 400 mbar $\leq pXe \leq$ 1000 mbar.

6. Lamp according to claim 1, 2, 3, 4 or 5, characterized in that the electrode diameter specified relatively to the average lamp current (Ila) at nominal lamp power fulfils the relation: $0.2 < (D_{electrode})^2 / Ila < 0.45$, preferably $0.25 < (D_{electrode})^2 / Ila < 0.35$ (narrow range).

7. Lamp according to claim 1, 2, 3, 4, 5 or 6, characterized in that the lamp emits light in nominal operating condition with a colour temperature T_C of at most 2500K.

ABSTRACT:

The invention is related to high pressure sodium lamp having a nominal power Pla. The lamp, which is designed to be operated at a very high frequency (VHF), has a discharge tube with a ceramic wall and an internal vessel diameter D_{int}, which encloses a discharge space in which a pair of electrodes at a mutual electrode distance ed and a filling of Na-amalgam with a sodium mol fraction (smf).

According to the invention the discharge tube has a ratio ed/ D_{int} of at most 7, preferably between about 5.5 and 4.0.

Fig. 5

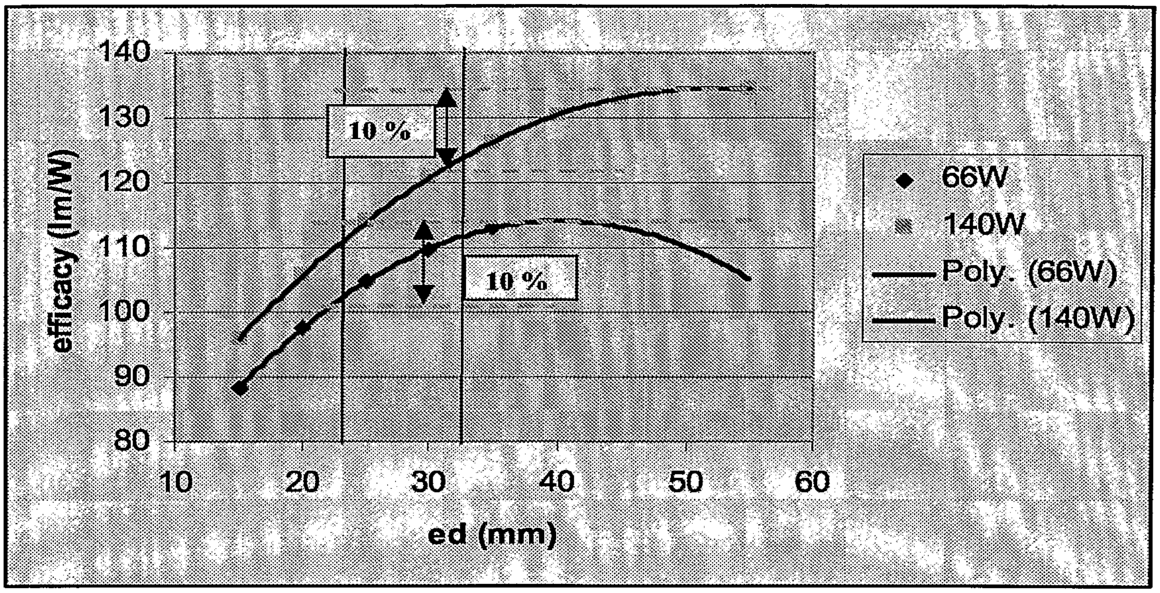

Figure 1 Calculated lamp efficacy of a 66 and 140W lamp according to the invention as function of ed. For the 66W lamp Vla = 55V, Pxe = 800 mbar, Twall = 1450 K, Dint = 4.5 mm, and the outer bulb is vacuum. The calculated wall thickness at ed= 22 mm is about .56 mm; the calculated smf is about 0.6. For the 140W lamp Vla = 55V, Pxe = 800 mbar, Twall = 1500 K, Dint = 6.3 mm, and the outer bulb is vacuum. The calculated wall thickness at ed= 32 mm is about .5 mm; the calculated smf is about 0.6.

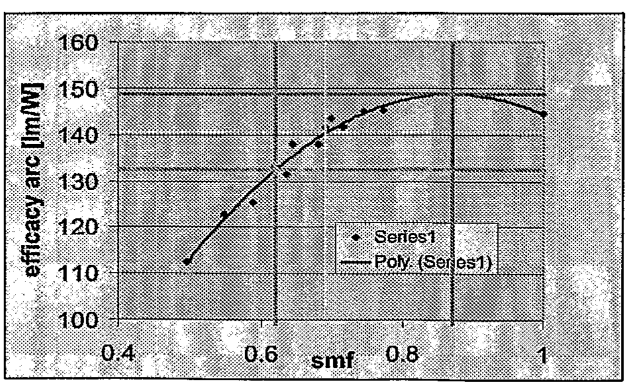

Figure 2 Efficacy of arc as function of the sodium mole fraction (all other parameters constant) The yellow and blue line indicate at which smf values respectively 95 and 90 % of the arc efficacy is achieved.

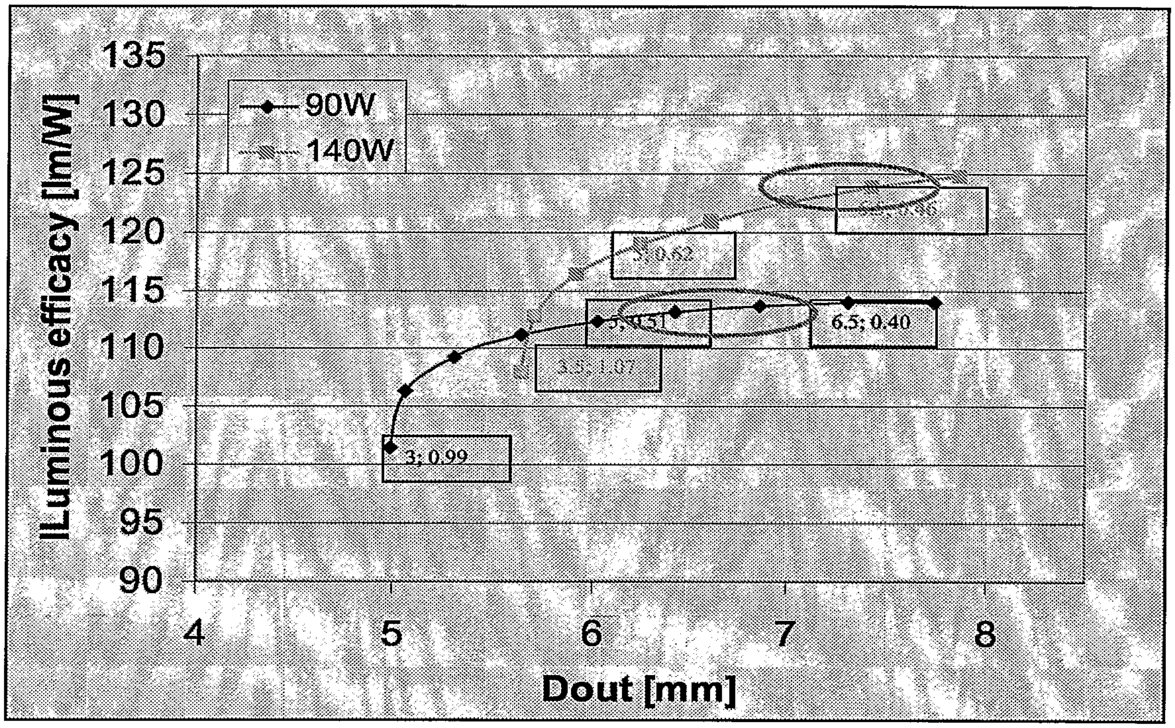

Figure 3. Luminous efficacy as a function of the outer diameter Dout at a wall temperature Twall of 1500K. For several points the internal diameter D_{int} and the wall thickness wt are indicated. Regions of optimal lamp designs are encircled.

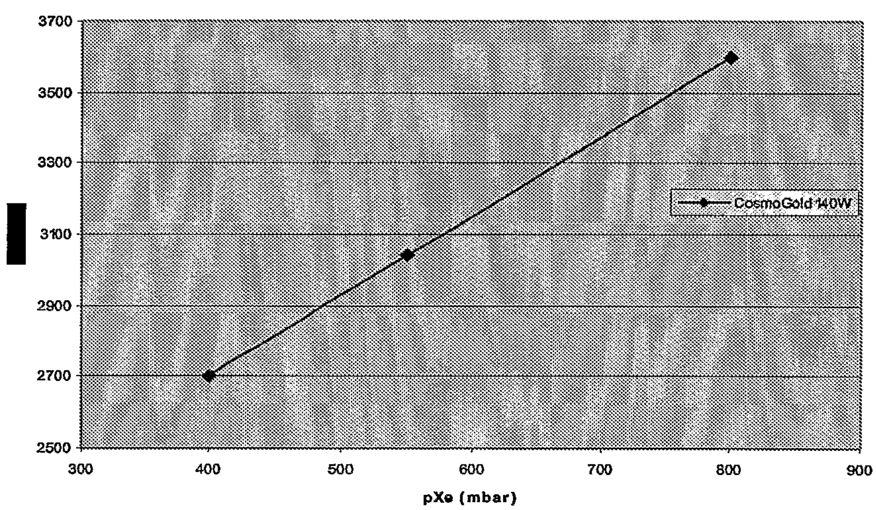

Figure 4.
Pulse ignition voltage as function of xenon pressure for a140W lamp according to the invention

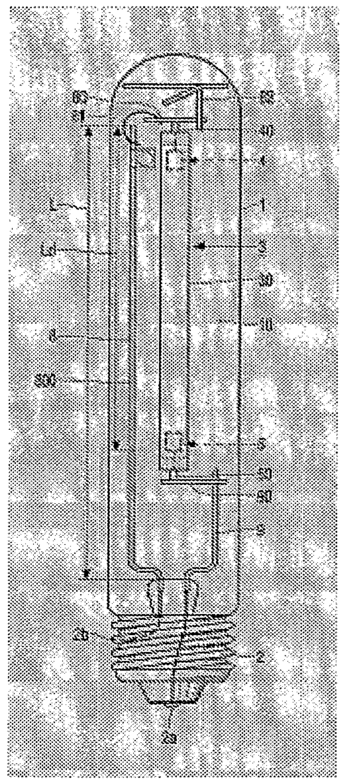

Fig. 5

PCT/IB2005/051117